NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
INVENTIONS AND CONTRIBUTIONS BOARD
SPACE ACT AWARD APPLICATION

BACKGROUND:

THE NASA SPACE ACT MONETARY AWARDS PROGRAM FOR SIGNIFICANT SCIENTIFIC AND TECHNICAL CONTRIBUTIONS

The objectives of this program are to provide official recognition of, and to grant equitable monetary awards for those inventions and other scientific and technical contributions that have helped to achieve NASA's aeronautical, commercialization, and space goals; and to stimulate and encourage the creation and reporting of similar contributions in the future. To accomplish these objectives, the Inventions and Contributions Board is authorized to recommend the granting of monetary awards in amounts up to $100,000 in accordance with the provisions of the National Aeronautics and Space Act of 1958, and to grant monetary awards in amounts up to $10,000 in accordance with the provisions of the Government Employees Incentive Awards Act of 1954. Space Act awards can be made to any person with no restriction as to employer, and in accordance with the regulations as specified in the Federal Register Vol. 55, No. 5, (14 CFR Part 1240). Awards made under the authority of the Incentive Awards Act can be made to U.S. Government employees only.

GUIDELINES:

In determining the merits of an invention or a contribution, the Board depends primarily on the information provided by the contributor(s)/technical evaluator in the Space Act Award Application. Furthermore, the Board recognizes that NASA technical personnel are the best sources of reliable information concerning contributions made by employees of NASA or by employees of NASA's contractors whose activities are under their cognizance. For this contribution, it is appropriate for the contributor(s)/ technical evaluator to supply the information that the Board requires in order to make a recommendation that is equitable to both the contributor(s) and NASA. We are therefore asking you to assist the Board by completing, accurately and thoroughly, the application which follows these explanatory remarks. For your convenience we suggest that you familiarize yourself with the contents of the application by reading it completely before answering the questions. Please provide all pertinent facts, specific details, explanations, and opinions regarding seven important factors that characterize the contribution. These factors are: (1) Description, (2) Significance, (3) Stage of Development, (4) Use, (5) Creativity, (6) Recognition and (7) Tangible Value. The Board welcomes any additional information that you believe will contribute to the completeness of its deliberations. If you find it necessary to modify or expand the format of the application in order to provide such extra information, please do so.

REQUIRED DOCUMENTATION AND AWARDS LIAISON OFFICE RESPONSIBILITY:

Please be thorough and candid with your evaluation. Each section must be filled in, and where appropriate, signed by the evaluators. **In no case should the evaluator be identified as a contributor**. The full legal name, home address and social security number for each contributor is mandatory and at least one NASA official must sign in Section II to attest to NASA's sponsorship, adoption, support or use of the contribution. If any supplementary materials are provided; e.g., additional sheets, technical papers, engineering drawings, videotape, audio cassettes, photographs, computer diskettes, etc., each must be marked and identified by the NASA Case Number. The names and contact information for individuals familiar with the contribution would be helpful for evaluation. The Awards Liaison Officer of the NASA Center where the contribution is supported is responsible for accepting the application and subsequent submission to the Board. Please ensure that the contributors have signed a Privacy Act statement such as that forwarded to the Awards Offices by the ICB on May 13, 1992. All contributions should be officially reported to NASA by submission of Form 1679 Disclosure of Invention and New Technology (Including Software).

The Board sincerely appreciates the time and effort you will devote to the completion of the Space Act Award Application. We pledge to take prompt action to review and process your application. It is our intent to expeditiously reward excellence.

NASA FORM 1329	Inventions and Contributions Board *Space Act Award Application*	NASA Case Number: ARC-15022	Date: April 14, 2006
SECTION I *SPACE ACT AWARD APPLICATION*			
TITLE **Data-Parallel Line Relaxation Code (DPLR)**			

1. **DESCRIPTION.**

   a. Briefly describe the contribution. In addition, if peer-reviewed publications by contributors have been accepted on this topic in refereed journals or for refereed conference papers, please attach a copy with this form as a supplement.

The DPLR software package is a suite of computational fluid dynamics (CFD) tools for the simulation of supersonic and hypersonic flows in chemical and thermal nonequilibrium. Included in the package are 2D/axisymmetric and 3D structured grid finite volume Navier-Stokes codes, a pre-processor, and post-processor, and user's manuals in PDF format for each tool. The CFD solver is written in Fortran 90 and supports distributed memory parallelism through the Message-Passing Interface (MPI) standard. DPLR has been developed and optimized for high parallel performance on a variety of dedicated shared and distributed memory supercomputer platforms as well as off-the-shelf workstation clusters. The code supports fully implicit boundary conditions, generalized multi-block grid topologies, and generalized chemical kinetics and thermodynamics property databases, and incorporates interfaces to other tools for thermal protection system (TPS) material response and shock layer radiation calculations. Pointwise boundary conditions are also fully supported, allowing the user great flexibility to apply material-specific "maps" with varying properties such as catalycity and emissivity, input profiles such as would be encountered in nozzle flows, and other complex boundary conditions. Surface boundary conditions include generalized models for homogeneous and heterogeneous catalysis, and allow loose coupling to material response codes for inclusion of ablating surface modeling.

There are many CFD codes available both within NASA and commercially, however few if any other than DPLR have the combination of accurate physical models for reentry flows and robust, efficient parallel performance necessary for the tool to be useful during preliminary and detailed mission design of planetary and Earth entry systems. Unlike typical supersonic or hypersonic aerodynamics CFD codes, a reentry aerothermodynamics code must solve additional conservation equations beyond the standard Navier-Stokes equations. For maximum performance, DPLR solves fully coupled species conservation equations for each reaction product (which can total dozens for combustion flows), as well as energy equations for each non-equilibrium energy mode. The modeling fidelity in DPLR is sufficient to solve perfect gas, dissociated, and weakly ionized flows in various states of nonequilibrium. Testing indicates that the code is very robust and exhibits a high parallel efficiency and scalability. DPLR has demonstrated order of magnitude improvements in solution time over the previous state of the art. DPLR was commercialized by the Ames Commercialization Technology Office (CTO) in June 2005 and has been released to over a dozen government agencies, industry partners, and universities to date.

The following is a partial list of the well over 100 conference papers, refereed journal articles, book chapters, and invited lectures that have been presented or published either about the DPLR software tool, or using the DPLR package for NASA-relevant research and analysis:

- Olejniczak, J., Wright, M.J., and Candler, G.V., "Numerical Study of Inviscid Shock Interactions on Double-Wedge Geometries." *Journal of Fluid Mechanics*, Vol. 352, 1997, pp. 1-25.

- Wright, M.J., Candler, G.V., and Bose, D., "Data-Parallel Line Relaxation Method for the Navier-Stokes Equations," *AIAA Journal*, Vol. 36, No. 9, 1998, pp. 1603-1609.

- Wright, M.J., Sinha, K., Olejniczak, J., Candler, G.V., Magruder, T.D., and Smits, A.J., "Numerical and Experimental Investigation of Double-Cone Shock Interactions," *AIAA Journal*, Vol. 38, No. 12, 2000, pp. 2268-2276.

- Wright, M.J., Loomis, M., and Papadopoulos, P., "Aerothermal Analysis of the Project Fire II Afterbody Flow," *Journal of Thermophysics and Heat Transfer*, Vol. 17, No. 2, 2003, pp. 240-249.

- Wright, M.J., Bose, D., and Olejniczak, J., “The Impact of Flowfield-Radiation Coupling on Aeroheating for Titan Aerocapture,” *Journal of Thermophysics and Heat Transfer*, Vol. 19, No. 1, 2005, pp. 17-27.

- Jits, R., Wright, M.J., and Chen, Y.-K., “Closed-Loop Trajectory Simulation for TPS Design for Neptune Aerocapture,” *Journal of Spacecraft and Rockets*, Vol. 42, No. 6, 2005, pp. 1025-1034.

- Wright, M.J., Prabhu, D.P., and Martinez, E., “Analysis of Apollo Command Module Afterbody Heating, Part 1: AS-202,” *Journal of Thermophysics and Heat Transfer,* Vol. 20, No. 1, 2006, pp. 16-30.

- Bose, D., Wright, M.J., Raiche, G., Bogdanoff, D., and Allen, G.A., ”Modeling and Experimental Validation of CN Radiation Behind a Strong Shock Wave,” AIAA Paper No. 2005-0768, Jan. 2005. Accepted for publication in the *Journal of Thermophysics and Heat Transfer,* Jul. 2005.

- Wright, M.J., Olejniczak, J., Brown, J.L., Hornung, H.G., and Edquist, K.T., ”Modeling of Shock Tunnel Heating Data on the Mars Science Laboratory Aeroshell,” AIAA Paper No. 2005-0177, Jan. 2005. Accepted for publication in the *Journal of Thermophysics and Heat Transfer*, Nov. 2005.

- Bose, D., Wright, M.J., and Palmer, G.E., ”Uncertainty Analysis of Laminar Aeroheating Predictions for Mars Entries,” AIAA Paper No. 2005-4682, Jun. 2005. Accepted for publication in the *Journal of Thermophysics and Heat Transfer,* Jan. 2006.

- Wright, M.J., Bose, D., and Chen, Y.-K., “Probabilistic Modeling of Aerothermal and Thermal Protection Material Response Uncertainties,” 53rd JANNAF Joint Propulsion Meeting, Dec. 2005.

- Lofthouse, A.J., Boyd, I.D., and Wright, M.J., “Effects of Continuum Breakdown on Hypersonic Aerothermodynamics,” AIAA Paper No. 2006-0993, Jan. 2006. In preparation for submission to *Physics of Fluids*.

- Wright, M.J., Brown, J.L., Sinha, K., Candler, G.V., Milos, F., and Prabhu, D.P., “Validation of Afterbody Heating Predictions for Planetary Probes: Status and Future Work,” *Proceedings of 2nd International Planetary Probe Workshop*, NASA CP 2004-213456, Apr. 2005, pp. 275-285.

- Wright, M.J. and Candler, G.V., “Data-Parallel LU Relaxation Method for Reacting Viscous Flows,” <u>Parallel Computational Fluid Dynamics – Implementations and Results Using Parallel Computers</u>, ed. A. Ecer et. al., Elsevier Science Publishers, pp. 67-74, 1995.

- Wercinski, P., Chen, Y.-K., Loomis, M., Tauber, M., McDaniel, R., Wright, M., Papadopoulos, P., Allen, G., and Yang, L., “Neptune Aerocapture Entry Vehicle Preliminary Design,” AIAA Paper No. 2002-4812, Aug. 2002.

- Takashima, N., Hollis, B., Zoby, E., Sutton, K., Olejniczak, J., Wright, M., and Prabhu, D., “Preliminary Aerothermodynamics Analysis of Titan Aerocapture Aeroshell,” AIAA Paper No. 2003-4952, Jul. 2003.

- Olejniczak, J., Wright, M., Prabhu, D., Takashima, N., Hollis, B., Zoby, E., and Sutton, K., “An Analysis of the Radiative Heating Environment for Aerocapture at Titan,” AIAA Paper No. 2003-4953, Jul. 2003.

- Olejniczak, J., Prabhu, D.K., Bose, D., and Wright, M.J., “Aeroheating Analysis for the Afterbody of a Titan Probe,” AIAA Paper No. 2004-0486, Jan. 2004.

- Reuther, J., Thompson R., M. Pulsonetti, M., and Campbell, C., “Computational Aerothermodynamic Analysis for the STS-107 Accident Investigation,” AIAA-2004-1384, Jan 2004.

- Reuther, J., McDaniel R., and Brown, J., Prabhu D., Saunders, D., and Palmer, G., “External Computational Aerothermodynamic Analysis of the Space Shuttle Orbiter at STS-107 Flight Conditions,” AIAA Paper No. 2004-2281, Jun. 2004.

- Bose, D., Wright, M., and Gökçen, T., “Uncertainty and Sensitivity Analysis of Thermochemical Modeling for Titan Atmospheric Entry,” AIAA Paper No. 2004-2455, Jun. 2004.

- Reuther, J., Prabhu, D., Brown, J., Wright, M., and Saunders, D., “Computational Fluid Dynamics for Winged Reentry Vehicles at Hypersonic Conditions,” AIAA Paper No. 2004-2537, Jun. 2004.

- Hollis, B.R., Wright, M.J., Olejniczak, J., Takashima, N., Sutton, K., and Prabhu, D., “Preliminary Convective-Radiative Heating for a Neptune Aerocapture Mission,” AIAA Paper No. 2004-5177, Aug. 2004.

- Olejniczak, J., Wright, M.J., Laurence, S., and Hornung, H.G., ”Computational Modeling of T5 Laminar and Turbulent Heating Data on Blunt Cones, Part 1: Titan Applications,” AIAA Paper No. 2005-0176, Jan. 2005.

- MacLean, M., Candler, G., and Holden, M., “Numerical Evaluation of Flow Conditions in the LENS Reflected Shock-Tunnel Facilities,” AIAA Paper No. 2005-0903, Jan. 2005.

- M. Holden, M., Harvey, J., MacLean, M., and Walker, B., “Development and Application of a New Ground Test Capability to Conduct Full-Scale Shroud and Stage Separation Studies at Duplicated Flight Conditions,” AIAA-2005-0696, Jan,. 2005.

- Hollis, B.R., Leichty, D., Wright, M.J., Holden, M., Wadhams, T., MacLean, M., and Dyakonov, A., “Transition Onset Correlations and Turbulent Heating Measurements for the Mars Science Laboratory Entry Vehicle,” AIAA Paper No. 2005-1437, Jan. 2005.

- Hollis, B.R., Striepe, S., Wright, M.J., Bose, D., Sutton, K., and Takashima, N., ”Prediction of the Aerothermodynamic Environment of the Huygens Probe,” AIAA Paper No. 2005-4816, Jun. 2005.

- Gökçen, T. and Stewart, D., “Computational Analysis of Semi-Elliptical Nozzle Arc-Jet Experiments: Calibration Plate and Wing Leading Edge,” AIAA-2005-4887, Jun. 2005.

- Marschall, J., Copeland, R., Hwang, H.H., and Wright, M.J., “Surface Catalysis Experiments on Metal Surfaces in Oxygen and Carbon Monoxide Mixtures,” AIAA Paper No. 2006-0181, Jan. 2006.

- Wright, M.J., Olejniczak, J., Walpot, L., Raynaud, E., Magin, T., Caillaut, L., and Hollis, B.R., “A Code Calibration Study for Huygens Entry Aeroheating,” AIAA Paper No. 2006-0382, Jan. 2006.

- Edquist, K.T., Wright, M.J., and Allen, G.A., “Viking Afterbody Heating Computations and Comparison to Flight Data,” AIAA Paper No. 2006-0386, Jan. 2006.

- Palmer, G.E., Olejniczak, J., and Wright, M.J., ”Uncertainty Analysis of Laminar Aeroheating Predictions for Titan Entries,” AIAA Paper No. 2006-0388, Jan. 2006.

- Johnson, H., Candler, G.V., and Wright, M.J., “Boundary Layer Stability Analysis of the Mars Science Laboratory Aeroshell,” AIAA Paper No. 2006-0920, Jan. 2006.

- Wright, M.J., Edquist, K.T., Hollis, B.R., Olejniczak, J., and Venkatapathy, E., “Status of Aerothermal Modeling for Current and Future Mars Exploration Missions,” Paper No. 2006-1428, IEEE Aerospace Conference, Big Sky, MT, Mar. 2006.

b. In what NASA program, project or mission has this contribution been used or will be utilized and to what extent? (include any non-aerospace commercialization applications)

Within NASA, DPLR has been used extensively at two field centers and within all four agency mission directorates. In the Space Operations Mission Directorate (SOMD), DPLR was used to define reentry aerothermal heating environments for the Shuttle Orbiter during the STS-107 accident analysis, Return to Flight (RTF) Program and STS-114 in-flight damage assessment analysis. DPLR, in conjunction with rapid grid generation tools, enabled same day turnaround analysis of the potential impact of observed damage scenarios, which allow engineers to make informed decisions on whether a given damage site should be repaired prior to entry. DPLR continues to be used in support of ongoing RTF activities at NASA Ames Research Center (ARC), Johnson Space Center (JSC), and Boeing Houston. In the Exploration Systems Mission Directorate (ESMD), DPLR is a primary tool employed by ARC and JSC for aerothermal and aerodynamic analysis of the Crew Exploration Vehicle (CEV) for the ESAS study, the CEV Aerosciences Project (CAP), and the Thermal Protection System Advanced Development Project (TPS-ADP). The convective heating portion of the CEV aerothermodynamic database is currently anchored primarily with CFD solutions generated with DPLR, and the code is also employed to design and analyze ground testing in hypersonic tunnels and arc jets. DPLR has also been coupled to a Monte-Carlo statistical analysis package and used to quantify uncertainties and sensitivities in the aeroheating environment in order to define TPS margins and reliability. In the Science Mission Directorate (SMD), DPLR is currently being used to define aeroheating environments and assess entry risks for the Mars Phoenix and Mars Science Laboratory missions, and was the primary aeroheating tool employed during entry risk analyses of the Stardust sample return capsule and Cassini-Huygens Titan entry probe. The code is also used extensively within SMD for early phase mission, proposal and concept studies involving planetary entry and technology demonstration missions, such as the proposed ST-9 aerocapture demonstrator. Finally, enhancement of both the physical models and underlying numerics of DPLR is a centerpiece of the fundamental hypersonic aerodynamics proposal within the Aeronautics Research Mission Directorate (ARMD). DPLR analysis is currently in the critical path of two of the agency's primary goals: Shuttle Orbiter Return to Flight and Crew Exploration Vehicle Development. There is no NASA Earth or planetary entry mission currently in the design, development, operational, or post-flight assessment phase for which DPLR is not playing an important role.

DPLR is also used in industry and academia for aerothermal analysis of the Shuttle Orbiter (Boeing Houston), tactical missiles and other DoD applications (Northrop-Grumman, AMRDEC, and Digital Fusion Solutions), and Air Force Office of Scientific Research (AFOSR) sponsored research activities (Boeing-Huntington Beach and the University of Minnesota). DPLR is the primary CFD tool used at the CalSpan University Buffalo Research Center (CUBRC), which operates the Large Energy National Shock Tunnel (LENS) facility for DoD and NASA research and analysis. Testing in the LENS facility, together with DPLR computational support for test design and analysis, were crucial to RTF and have recently been used to explore previously undocumented high turbulent heating levels on the Mars Science Laboratory aeroshell. LENS testing is also planned for CEV design, and will be supported by DPLR pre and post test analysis. Finally, DPLR has been used by the University of Minnesota in several DARPA and AFOSR sponsored projects, including the supersonic inlet design for the HyCause scramjet flight test. Although DPLR has only been formally available for about one year, the Ames CTO office receives frequent requests for release. Most recently, DPLR is being considered to be the primary CFD analysis tool in the AFOSR/industry/academia turbulent transition research program.

c. Provide details describing how the contribution works or operates relative to system, subsystem, components, etc.

DPLR is a hypersonic reacting flow CFD code, and produces as output predictions of the incident aeroheating environment and aerodynamic properties for use in vehicle, trajectory, and thermal protection system design. DPLR is generally used in conjunction with other design software to perform trajectory, material response, structural, and thermal analysis, and includes "hooks" or interfaces to facilitate loosely coupled interaction with those tools. The DPLR package consists of four primary tools: a pre-processor (FCONVERT) for grid manipulation and parallel decomposition, a two-dimensional/axisymmetric CFD code (DPLR2D), a three-dimensional CFD code (DPLR3D), and a post-processor (POSTFLOW), which extracts desired data from the computed solution in the user-requested format. The use of each of these tools, including all available options, is detailed in the user's manual for each, and is briefly discussed here.

FCONVERT: In typical operation the user imports a grid into DPLR format and prepares the problem for execution using FCONVERT. The primary function of FCONVERT is decomposition of the input grid file for efficient execution on a parallel machine. DPLR deals with two levels of block decomposition: master blocks, defined by the grid topology chosen, and parallel blocks, which are created "virtually" by FCONVERT by decomposing the master blocks into multiple sub-blocks for efficient load-balanced execution on the available processors. An important feature of DPLR is the distinction between these two levels; while in practice a large problem may be decomposed into hundreds of small blocks for efficient execution, the user only needs to be aware of the (much smaller) number of master blocks. This greatly simplifies problem setup and post-processing, and makes it trivial to change the number of processors that the job is executed on from run to run if necessary. In addition to parallel decomposition, FCONVERT also performs other functions, including mesh sequencing, file format conversion, and the importing of restart files from other programs or applications.

DPLR2D/DPLR3D: Then the CFD simulation is performed using either DPLR2D or DPLR3D. It is important to note that, while these are separate executables (primarily for performance reasons), they share approximately 90% of the same source code, minimizing the chance for coding errors in one of the programs. DPLR employs the highly efficient data-parallel line relaxation method for implicit time advancement. This method was developed specifically for parallel execution, and has proven to be efficient on both shared and distributed memory machines. DPLR employs the MPI standard (and is fully compatible with MPI2), ensuring ready portability to a wide variety of computer platforms. To date DPLR has been successfully compiled and run on the CM-5, Cray XMP and T3-D/E series, IBM SP and SMP series, the SGI Origin and Altix, and many types of commodity workstation clusters running LINUX or Mac OS-X. In part because of its ready portability to a wide variety of platforms, DPLR stores all binary information in platform-independent eXternal Data Reference (XDR) format, which means that datafiles generated on one machine can be used on another without conversion. In addition to its basic execution mode DPLR has several features that enhance solution quality, including automatic grid alignment and the ability to change the number of simulated species, thermal nonequilibrium modes, and turbulence variables "on the fly". DPLR also has extensive error trapping built in and attempts to detect common setup or runtime errors and provide information to the user to assist in diagnosis. During startup DPLR will input three classes of message to standard output: informational messages simply list physical and numerical models employed, warning messages are provided when DPLR detects a condition that is likely (but not automatically) an error, and finally error messages are provided when a fatal error is detected. Of the three only error messages cause termination of the run.

POSTFLOW: Once the CFD solution has been obtained the user employs POSTFLOW to extract the desired information for post-processing and data visualization. POSTFLOW is an extremely powerful tool that can extract several hundred derived flow quantities in user specified volume and/or surface subsets. POSTFLOW can also perform standard integrated aerodynamics calculations (forces and moments), and automatically accounts for problem symmetries during output. Finally, POSTFLOW can be used to extract freestream properties, global minima/maxima, and the location of NaN's in the dataset (for debugging purposes). The user has complete control over all of these options; i.e. which variables to write over which portion of the solution domain. POSTFLOW also supports the automatic extraction of user-specified boundary faces, which greatly simplifies this process on large multiblock grid systems. The fluid and chemistry calculations performed within POSTFLOW to determine derived output variables are done by linking to the same subroutines used within DPLR, ensuring consistency. One unique feature of DPLR is that all of the physical property data used to generate the solution is embedded into the restart file, which ensures that POSTFLOW generated datasets will always be consistent with the CFD solution, even if the physical property database has been altered since the case was run.

All three codes have been written to ensure robust performance, and are amenable to scripted execution, making them useful for rapid parametric design or optimization studies. This capability has already been demonstrated by coupling DPLR to a Monte-Carlo statistics package and demonstrating fully probabilistic aerothermal heating analyses for planetary entry problems by generating statistics from thousands of full body CFD calculations on in a few days on a commodity workstation cluster (the resultant paper won an AIAA best paper award in 2004).

2. SIGNIFICANCE.

a. Explain why the contribution is significant: scientifically, technologically, or from a humanitarian viewpoint, to the aeronautics, space community, and non-aerospace commercial activities.

DPLR has potential use for all NASA Earth reentry, hypersonic aerodynamics, and planetary entry missions, as well as DoD and commercial aerospace applications. DPLR is already heavily used by three of four agency mission directorates, and is a centerpiece for future technology development in the fourth. DPLR is currently on the critical path for two of the three primary agency priorities: the Shuttle Orbiter and the Crew Exploration Vehicle, and is supported and used by the agency lead (Johnson Space Center) for both of these programs. DPLR has also been released by the CTO office at Ames, and the steady stream of requests from Industry and Academia testify to its potential contributions in the civilian and military aerospace industries. The advances to the state of the art embodied within DPLR have greatly increased the utility (and turnaround time) of high-fidelity CFD analysis during early mission design phases, and for near real-time assessment of mission risk of operational vehicles. In addition, the application of DPLR to mission critical ground test design and analysis have the potential to greatly increase the value of this testing, which could result in cost savings (through reduced testing), or more likely increased system reliability (through increased return from the testing performed).

b. Estimate the degree of scientific or technological significance by a mark on the line below:

0___________1_______________2___________________3_________ _______4________X_______5

None ***Modest*** ***Average*** ***Major*** ***Maximum***

c. Estimate the significance of the contribution relative to a specific NASA program or mission by marking the line below:

0___________1_______________2___________________3_________________4_______X________5

None ***Modest*** ***Average*** ***Major*** ***Critical***

3. STAGE OF DEVELOPMENT.

Indicate the stage of development of the contribution by a mark on the line below:

0___________1_______________2___________________3_________________4_______X________5

Concept ***Simulated*** ***Tested*** ***Fully Developed*** ***Operational***

4. ASSESSMENT OF USE.

a. If the contribution is now in operation, describe its performance and value within both the aerospace field and its application to non-aerospace commercial and government uses.

DPLR is currently in daily use at ARC (two divisions), JSC, DoD, numerous universities, and several industrial sites, including many of the primary NASA spacecraft hardware contractors. In addition, a preliminary request has been made by Sandia National Labs (DoE). See attached letters of endorsement for an assessment of the value of the software to these institutions. The software has its primary use within the aerospace industry. The commercial use of the software is somewhat limited by its restricted availability (US persons only), but the very nature of this restricted availability makes DPLR that much more valuable within the US aerospace industry, since commercial options are not available.

b. If the contribution is not now in operational use, describe its most likely or previous applications and the extent of commercial, (includes non-aerospace commercialization) government and/or NASA-specific uses.

Currently in operational use.

c. Will the contribution increase in value or in its applications over time and in what manner?

It is expected that the utility of DPLR will continue to grow with time as additional physical models and numerical enhancements are incorporated into the code. Planned enhancements include tight coupling to material response and radiation codes (for CEV applications), time accurate aeroelastic simulations (supported by ARMD for entry, descent and landing tool development, overset grid capability (for the Shuttle Orbiter and future hypersonic cruise vehicles). In addition, DPLR has recently been coupled to a Monte-Carlo based uncertainty analysis toolkit that has for the first time enabled probabilistic uncertainty analysis directly using high fidelity reacting gas CFD solvers. This methodology has great potential for increasing reliability estimates and reducing system mass for future thermal protection system designs. While DPLR is firmly entrenched within NASA, it has only been a released software for about nine months. Given the amount of early interest in the code we fully expect its contributions to DoD, DoE and civilian aerospace industry to increase greatly with time.

5. CREATIVITY.

What is your assessment of the creativity displayed in the conduct of this contribution, relative to the expected performance of those in similar positions?

*None*________*Low* __________*Modest*_________*Average*________*High*________*Very High*_____X_____

6. RECOGNITION

What forms of recognition have been received by the contributors for this contribution? Have previous awards been made to the contributor(s) for this accomplishment? Please describe.

The authors of the DPLR software code received a “software release award” in 1995. In addition, the authors and users of DPLR have received multiple NASA and NESC achievement and turning goals into reality (TGIR) awards for their work. DPLR users have also received the Silver Snoopy award for their contributions to the STS-114 flight, and a Space-Act award for a heatshield design patent arising out of DPLR analysis performed during the ESAS study. Publications based on DPLR simulations have twice been named the AIAA best technical paper in Thermophysics award (2001 & 2004). Dr. Wright has given multiple invited lectures and seminars at domestic and international universities based in part on the capabilities of the DPLR code.

7. **TANGIBLE VALUE**.

As a measure of the tangible value of this contribution, estimate the following:

a. NASA cost savings* to date and in future years.

DPLR3D allows the analyst to perform simulations on complex geometries including a fidelity of physical modeling that was previously intractable. Via a combination of a new and efficient implicit algorithm and highly optimized execution on a variety of parallel platforms DPLR has reduced the wall-clock time to solution for complex three-dimensional full vehicle entry simulations by almost two orders of magnitude over the previous state of the art. Of course, these "cost savings" are typically used to perform a larger number of simulations over a wider range of conditions than before, and to inject high-fidelity analysis earlier into the design cycle. This in turns translates into improved knowledge and understanding of a vehicle's performance, and the risk and reliability of the resulting thermal protection system design. Since the TPS is a single point of failure non-redundant system for any planetary or Earth entry vehicle, the resulting increased understanding is difficult to quantify in monetary terms when crew and payload safety are paramount.

Ground (or flight) testing will always be required for entry vehicle analysis, because the physical phenomena involved are highly complex. However, the use of DPLR as a design and analysis tool can help to maximize the efficiency of the required ground testing, which can result in significant cost savings. For example, arc jet testing for TPS design and analysis currently costs about 300K/week at NASA ARC; even a small reduction in required testing (or corresponding increase in data return) could quickly add up to large cost savings for a program.

The NASA missions currently supported by DPLR include some of the largest and most expensive agency programs (including Shuttle, CEV, and MSL). Clearly even a small increase in mission safety and reliability, or a small decrease in subsystem uncertainty and risk, will have a very large payoff in terms of the ability of the agency to successfully and safely meet the expectations of the public.

b. Current market value and potential as a commercial product or process.

The primary utility of DPLR is limited to the aerospace and combustion industries, but the software has potential customers at all NASA centers, multiple DoD organizations, and all major aerospace contractors. DPLR can also be used as an educational tool at US Universities. Assuming an industry average per seat cost of $20000 and a possible number of seats of 250, the potential market value is approximately $5 million in seat fees, and approximately 20% per year in support and upgrade fees. (There are currently approximately 50 unique users, and an assumption of 250 in time is a conservative value).

c. Other measurable value: increased efficiency, enabling technology, improved management, etc.

The efficiency advances embodied in DPLR have resulted in a situation where CFD simulations for reentry flows are no longer limited by the algorithm itself, but rather by the uncertainties inherent in the physical models employed. DPLR is attacking this problem as well, providing users with an unprecedented set of physical modeling choices, including thermal and chemical nonequilibrium models for entry to all atmosphere bearing bodies in the solar system, generalized boundary conditions that allow the user to enter desired surface and gas phase reactions and their rates, and interfaces to other high-fidelity design tools to facilitate coupled analysis of the next generation of complex entry systems. In addition, DPLR has been coupled with a Monte-Carlo statistics package, which has enabled users to predict both the uncertainties and corresponding sensitivities inherent in the models employed for the first time.

APPLICANT'S SIGNATURE: ______________________ DATE: ____________

APPLICANT'S SIGNATURE: Matth Mal **DATE: 04/13/06**

APPLICANT'S SIGNATURE: ______________________ DATE: ____________

APPLICANT'S SIGNATURE: ______________________ DATE: ____________

APPLICANT'S SIGNATURE: ______________________ DATE: ____________

**State the rationale for the above cost estimates.*

SECTION II COMMENTS AND CONCURRENCE

1. EVALUATOR

I recommend/do not recommend a Space Act Award for this contribution for the following reasons.

Printed Name and Signature	Title	Date
Dr. Nagi N. Mansour	Chief, Reacting Flow Environments Branch	April 14, 2006
NASA Installation	**Contractor**	**Other**
NASA Ames Research Center		

2. EVALUATOR'S SUPERVISOR

I support a Space Act Award for this contribution for the following reasons:

- Instrumental in aerothermal analysis in support of Columbia accident investigation.
- Primary analysis tool in identifying need to remove gap fillers on STS-114
- Primary aerothermal analysis tool supporting CEV TPS development
- Primary aerothermal tool supporting Mars Phoenix, MSL and Stardust risk review missions

Printed Name and Signature	Title	Date
Dr. Charles A. Smith	Chief, Space Technology Division	April 14, 2006

3. TECHNICAL MANAGEMENT

I support/do not support a Space Act Award for this contribution for the following reasons.

Printed Name and Signature	Title	Date
Dr. Eugene L. Tu	Director, Exploration Technology Directorate	April 14, 2006

4. COMMERCIALIZATION MANAGEMENT

I support/do not support a Space Act Award for this contribution for the following reasons.

Printed Name and Signature	Title	Date

TO BE COMPLETED BY AWARDS LIAISON OFFICE

5. IDENTIFICATION OF CONTRIBUTORS

Name, Employer, and Percent Contribution	Social Security Number	Home Address
Michael Wright NASA Ames Research Center 65% contribution		
Matt MacLean CUBRC 10% contribution		
James Brown		

NASA Ames Research Center 10% contribution	
David Saunders ELORET Corporation 10% contribution	
Ryan McDaniel NASA Ames Research Center 5% contribution	

NASA Case Number
ARC-15022

6. PATENT INFORMATION

Patent Applied for? Y/N Granted? Y/N	Serial Number or Patent Number
N	
Application filed by: Government? Non-Government?	Date Filed or Granted
License Granted Y/N N	Company Name:

7. EVALUATION NUMBER 1 2 3

8. BUSINESS ADDRESS OF CONTRIBUTORS IF OTHER THAN NASA EMPLOYEES

Matt MacLean, CUBRC, 4455 Genesee St., Buffalo NY 14225
David Saunders, ELORET Corporation, 465 S. Mathilda Ave, Suite 103, Sunnyvale CA 94087

9. AWARD LIAISON OFFICER COMMENTS AND SIGNATURE

Printed Name and Signature	Comments	Date